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TITLE OF THE INVENTION (280 characters max)

LENS ACTUATOR ASSEMBLY FOR OPTICAL HEAD

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Respectfully submitted,

BROWDY AND NEIMARK, P.L.L.C.

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LENS ACTUATOR ASSEMBLY FOR OPTICAL HEAD

FIELD OF THE INVENTION

This invention relates to lens actuator assemblies, and in particular to such assemblies that allow tight focusing of a beam of electromagnetic radiation while recording/reading information at a plurality of locations in a three-dimensional optically scannable information carrier.

BACKGROUND OF THE INVENTION

Three-dimensional optical memory devices or information carriers have been developed being aimed at significantly increasing the amount of recordable data, as compared with conventional two-dimensional devices (typically two data-layer containing structures). Optical storage devices have customarily been dependent on the ability to focus a laser beam to a tight spot of the order of its diffraction limit so as to allow for squeezing as much information as possible onto the surface of the storage device. This requires correction for optical aberrations.

The inventors have found that correcting spherical aberrations over a predefined thickness of a specific material for specific wavelengths may be achieved by using only two separate optical assemblies - a first, main lens assembly that performs the majority of the light bending required for the focusing of light, and a second auxiliary lens assembly (corrector) that mainly compensates for the changing spherical aberration introduced by the changing of the thickness into which the light is being focused. Generally, aberration types that can be corrected are those induced by light traversing through varying depth within the disk material and include for example spherical aberrations

In US 5,712,842, an optical head is described having an objective lens mounted on a first holder and comprising a first actuator for moving the lens along the optical axis. A solid immersion lens, for the purpose of providing a

large numerical aperture, is arranged between the objective lens and the information carrier to be scanned, and mounted onto a second lens holder which is in turn mounted onto the first holder. The objective lens and the solid immersion lens are jointly moved parallel to the optical axis by means of the first actuator so that the scanning spot may be focused on the information layer of the information carrier. A second actuator is provided for enabling movement of the second lens holder and solid immersion lens independent of the movement of the objective lens, so that the spherical aberration of the radiation beam in the transparent protective layer of the information carrier present between the information layer and the scanning device may be corrected. Thus, the objective lens focuses a radiation beam onto the information carrier, while the solid immersion lens enables the scanning device to have a large numerical aperture and thus scan information carriers having relatively small elementary information characteristics, i.e., high information density.

In US 6,310,840, a similar system to that of US 5,712,842 provides a large numerical aperture, but in US 6,310,840 the arrangement of the actuators is reversed with respect to that of US 5,712,842. Thus, in US 6,310,840, the objective lens holder is mounted with respect to the solid immersion lens holder, and the combination is actuated by the first actuator. A second actuator enables the objective lens holder to be displaced with respect to the solid immersion lens holder. Thus, the necessary power required to operate the first actuator is considerably reduced.

In both references, the auxiliary lens has a planar side facing the optical carrier, and a highly convex side facing the main lens, and the auxiliary lens is provided for the purpose of increasing the numerical aperture of the lens system. None of these references is concerned with focusing the radiation beam with respect to any one of a plurality of information layers within a three-dimensional information carrier.

SUMMARY OF THE INVENTION

In operation, the lens actuator assembly thus comprises two lens assemblies accommodated in an optical path of the exciting and excited light beams and being arranged in a spaced-apart relationship along an optical axis of the optical module arrangement. According to the present invention, one of these two lens assemblies is designed to perform the majority of light bending required for the focusing of the exciting light and collecting the excited light, and the other lens assembly is designed to compensate for changing spherical aberration introduced by a change in a thickness of the medium into which the exciting light is being focused. The lenses of the focusing/collecting arrangement have different surface geometries, at least one of these surfaces being aspheric.

Preferably, that one of the two lens assemblies which is designed to compensate for changing spherical aberration is located closer to the medium. One of the two lens assemblies which is designed to perform the majority of light bending may be configured to define two lens portions of different materials and geometries. In this case, the lens portions may be separate lens elements arranged in a spaced-apart relationship along the optical axis either with a gap between them or being attached to each other.

Alternatively, that one of the two lens assemblies which is designed to perform the majority of light bending may be located closer to the medium. In this case, the other one of the two lens assemblies may be a multiple-lens assembly, for example including three spaced-apart different lenses.

The variation of the depth of focus is preferably implemented by displacing at least one of the lenses of the focusing/collecting arrangement with respect to at least one other lens thereof along the optical axis, and more preferably displacing only that one of the lens assemblies which is designed to perform the majority of light bending. Generally, however, the entire focusing/collecting arrangement, as well the light source and detector assembly can be movable with respect to each other and/or with respect to the medium.

The correction of chromatic aberrations of focusing/collection may be carried out during the exciting beams' propagation towards the focusing/collecting arrangement and the excited beam propagation from the focusing/collecting arrangement, by pre-shaping the exciting beams and post-shaping of the collected excited beam, while correction of spherical aberration is carried out by the focusing/collecting arrangement. The pre-shaping consists in providing a desired degree of the beam divergence or convergence when arriving at the focusing/collecting arrangement. Several examples of pre-shaping are possible: The pre-shaping may consist in providing a slight divergence or convergence of each of the exciting beams, thereby providing semi-infinite conjugation of the exciting beams. The pre-shaping may consist in providing a larger degree of divergence or convergence of each of the exciting beams, so as to provide finite conjugation of the exciting light beams. The pre-shaping may consist in collimating one of the first and second exciting light beams and providing a slight divergence/convergence of the other exciting beam when arriving to the focusing/collecting arrangement so as to provide the semi-infinite conjugation of said other beam. The pre-shaping may include collimation of each of said first and second exciting light beams. The post-shaping of the excited light beam consists of providing a desired divergence or convergence of the excited beam when arriving at the detector assembly.

The first and second exciting beams may be, respectively, reading and recording light beams, or both be reading or recording light beams.

Thus, the present invention is directed to a lens actuator assembly for an optical head comprising:

a lens system comprising a first lens arrangement and a second lens arrangement for focusing a beam of radiation in a focusing direction;

a first electromagnetic actuator for actuating at least said first lens arrangement in a focusing direction;

a second electromagnetic actuator for actuating at least said second lens arrangement in a focusing direction;

wherein a common magnet arrangement provides a suitable magnetic field common to both said actuators, enabling operation of each said actuator when a suitable electric current is provided thereto.

In preferred embodiments, the first actuator comprises a pair of first coils one each mounted to opposed ends of a housing, said housing accommodating said first lens at an aperture thereof aligned in said focusing direction. The magnet arrangement comprises a first plate magnet mounted to a base in opposed relationship to one said first coil and a second plate magnet mounted to said base in opposed relationship to the other said first coil. The housing is elastically mounted to said base such as to enable said housing to move in at least said focusing direction while maintaining alignment between said first coils and said first and second plate magnets. The housing is mounted to said base via a plurality of resilient members connected at one end thereof to said base and at another end thereof to said housing.

The first and second plate magnets each comprise a first pair of bar magnets aligned in series in the focusing direction and arranged such that for each said pair of bar magnets, each bar magnet exposes a different pole with respect to a said first coil that is mounted in opposition thereto. The first coils are substantially rectangular, each said first coil comprising a pair of coil arms each of which is substantially aligned with a corresponding pole of a said first pair of bar magnets that is mounted in opposition to said first coil. The second lens arrangement is accommodated in a lens holder at an aperture thereof aligned in said focusing direction, wherein said lens holder is elastically mounted to said housing via a suspension system.

The second actuator comprises a pair of second coils mounted to opposed ends of said lens holder. Each one of the second coils is in substantially opposed relationship with respect to one or another said first pair of bar magnets. The second coils are substantially rectangular, each said second coil comprising a pair of coil arms each of which is substantially aligned with a corresponding pole of a bar magnet of said pair of bar magnets that is mounted in opposition to said first

coil. The suspension system is configured to enable said lens holder to move in at least said focusing direction while maintaining alignment between said second coils and said first and second plate magnets. Further, the suspension system is particularly configured to enable said lens holder to move in at least said focusing direction while substantially maintaining alignment, and thus avoiding decentering or tilt, between said first lens arrangement and said second arrangement along an optical axis of said lens system.

In the first embodiment, the suspension system comprises first and second mounting elements spaced one from the other along the focusing direction and each extending transverse from the focusing direction, each mounting element being elastically deformable along the focusing direction. The first mounting element is mounted to said housing, and wherein said second mounting element is mounted to said lens holder. The first mounting element is connected to said second mounting element via substantially rigid spacing members at the transverse ends of said mounting elements. The first and second mounting elements each comprise a pair of leaf springs joined to a central mounting ring.

In the second embodiment, the said suspension system comprises a first pair and a second pair of mounting elements spaced one from the other along the focusing direction and each extending transverse from the focusing direction, each mounting element thereof being elastically deformable along the focusing direction. The first pair of mounting elements is mounted to said housing at opposed inner sides thereof, and wherein said second pair of mounting elements is mounted to said lens holder one each at an upper end and lower end thereof. The first pair of mounting elements is connected to said second pair of mounting elements via substantially rigid spacing members at the transverse ends of said mounting elements. Each said mounting element said first and second pair of mounting elements comprises a pair of leaf springs joined to a central mounting ring.

Preferably, the lens actuator further comprising a third electromagnetic actuator for actuating at least said first lens arrangement in a tracking direction

substantially orthogonal to said focusing direction. The third actuator comprises at least one pair and preferably two pairs of third coils mounted to said opposed ends of said housing. An auxiliary magnet arrangement provides a suitable magnetic field to said third actuator, enabling operation of said third actuator when a suitable electric current is provided thereto. The auxiliary magnet arrangement comprises, for each said third coil, a second pair of bar magnets mounted to said base in opposed relationship to said third coil. Each second pair of bar magnets is aligned in series in the tracking direction and arranged such that for each said second pair of bar magnets, each bar magnet exposes a different pole with respect to a said third coil that is mounted in opposition thereto. Each third coil is positioned adjacent to a corresponding said first coil at each said end of said housing along said tracking direction. The third coils are substantially rectangular, each said third coil comprising a pair of coil arms each of which is substantially aligned with a corresponding pole of a said second pair of bar magnets that is mounted in opposition to said third coil.

The second lens is typically an objective lens and said first lens is an auxiliary lens. The lens system is adapted for enabling a beam of radiation to be focused at any desired depth within a three-dimensional optical data carrier; the depth is typically in the range of about 0 to about 3mm. The lens system is adapted for enabling a beam of radiation to be focused at any desired depth within a range of depths such as to enable said beam to be focused at a data layer of an information carrier, wherein said information carrier may include any one of a range of different types of information carriers each having at least one data layer at a different depth within said range of depths. The different types of information carriers may include at least one of a CD, a DVD and a BluRay disc.

The first lens arrangement is typically positioned about 100 microns to about 400 microns from the surface of an information carrier that it is intended to read/write information with respect to. The first lens arrangement may include a meniscus lens, and the second lens arrangement may include a biconvex lens.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to understand the invention and to see how it may be carried out in practice, a preferred embodiment will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

Fig. 1 is an exploded isometric view of the first embodiment of the present invention.

Fig. 2 is a collapsed isometric view of the embodiment of Fig. 1.

Fig. 3 is an exploded isometric view of the main lens assembly of the embodiment of Fig. 1.

Fig. 4 is a collapsed isometric view of the main lens assembly of Fig. 3.

Fig. 5 is an isometric view of the magnet arrangement of the embodiment of Fig. 1.

Fig. 6 is an exploded isometric view of the second embodiment of the present invention.

Fig. 7 is an exploded isometric view of the main lens assembly of the embodiment of Fig. 6.

Fig. 8 is a collapsed isometric cross-sectional view along the focus/tracking plane of the main lens assembly of Fig. 7.

DETAILED DESCRIPTION OF THE INVENTION

Herein, the term "focusing direction" refers to a direction substantially perpendicular to the plane comprising the information that it is required to read from or write to in an optically scannable information carrier, such as a DVD or CD, and particularly a three-dimensional storage medium or multi-layer carrier, typically in the form of a disc. The focusing direction coincides with the optical axis of the optical head. The term "tracking direction" refers to a substantially radial direction with respect to the carrier, and the term "tangential direction" refers to a direction substantially tangential to the carrier.

The construction of the optical information carrier does not form part of the present invention, except to note that may be one of ROM (Read Only Memory), WORM (Write Once Read Many), and recordable (rewritable) memory types. More specifically, the present invention is preferably used with a data storage medium in the form of a monolithic translucent substrate. The monolithic nature of the storage material entails a uniformity of the optical parameters of the carrier – typically shaped as a disk - resulting in a homogeneous index of refraction and absorption coefficient throughout the disk. This allows for designing the focusing device with an aberration corrector of a known range of motion and overall behavior. The disk may for example be designed as described in WO 01/73779 and WO 03/070689, both assigned to the assignee of the present application. According to this technique, the substrate medium (active medium, e.g., including diarylalkene derivatives, triene derivatives, polyene derivatives or a mixture thereof) is of the type capable of changing from a first isometric form to a second isomeric form in response to a light beam having energy substantially equal to first threshold energy. The concentration ratio between the first and second isomeric forms in any given volume portion represents a data unit. The active medium may be embedded in a supporting matrix, which may be a polymer, and the active medium is chemically bound thereto. Alternatively the supporting matrix may be a wax or a micelle and the active medium is homogeneously distributed therein. The information is stored as a series of data units. Data reading is based on reading data units from the isomeric states of the active medium in different portions of the active medium, where the two isomeric forms have a substantially different absorption coefficient for absorbing energy of second threshold energy. Reading may also be carried out by measuring the scattering pattern of the two isomeric forms. The disk may be provided with a specific coating, for example for the purposes of protecting it against UV radiation. The disk may for example be protected within a cartridge.

In the monolithic active medium, a data layer is considered as one data set inscribed at a specific depth (within a specified tolerance). Layers with very tight depth tolerance can be considered as having fixed depth. Layers with loose depth

tolerances will be termed as layers with variable depth. Data is recorded (written/erased) in a specified layer by changing the state of the substrate within a localized volume element, defined by the focus of the read/write/erase optical beams. The present invention provides for dynamic focusing of light beams of different wavelengths in a large number of layers with fixed depths, and in a large number of layers of variable depth.

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While reading/recording data in a three-dimensional storage medium (e.g., a monolithic translucent material), incident light beams of different wavelengths after passing through a lens arrangement traverse two distinct materials (e.g., air followed by a clear plastic) and is focused within the second material (storage medium). Correction of chromatic and spherical aberrations may be provided by tailoring the focusing/collecting arrangement to enable focusing of two exciting light beams of different wavelengths onto desirably distanced from each other sites in the medium and detecting excited light coming from the medium while correcting for chromatic and spherical aberrations of focusing/collection. This is implemented by appropriately designing the focusing/collecting arrangement (i.e., a number of lenses, their relative accommodation and geometry) to adjust a degree of divergence/convergence of the exciting light beams' when arriving to the focusing/collecting arrangement, as well as the collection of the excited light, and the light propagation in between the focusing/collecting arrangement and the medium. It should be noted that with regard to excited light, the focusing/collection assembly receives a portion of this light impinging onto the focusing/collecting arrangement and forms an excited light beam to propagate towards a detector assembly. Thus, the term "excited light beam" or "excited beam" used herein signifies either one of excited radiation or shaped excited beam, depending on the excited light propagation location, namely, respectively, between the focusing/collecting arrangement and the medium, and between the focusing/collecting arrangement and a detector assembly.

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The focusing and collecting include passing the exciting light beams and the excited light through the same focusing/collecting arrangement. The geometry of the focusing/collecting arrangement and its accommodation relative to the medium and to light source and detector assemblies are optimized to be capable of focusing each of the exciting light beams to said desirably distanced from each other sites in the medium and detecting the beam of the collected excited light coming from the excited site in the medium.

Referring to Figs. 1 and 2, a first embodiment of the lens actuator assembly for an optical head, generally designated with the numeral **10**, is illustrated in isometric view, exploded and collapsed, respectively. In operation, the lens actuator assembly **10** is controlled by actuators in both the focus and tracking drive directions, as will be described in greater detail hereinbelow. Further control of the radial direction enables the lens actuator assembly **10** to move from one track to another track within the carrier, and many arrangements for so doing are known in the art and will not be described further herein.

In the first embodiment, the lens actuator assembly **10** comprises a corrector lens assembly **15**, comprising a lens holder **20**, which is generally box like and preferably in the form of an inverted U-section, having an upper opening **21** in which a correcting lens **30** is mounted. The correcting lens **30** is aligned with the optical axis **OA** of the lens actuator assembly **10**. The corrector lens assembly **15** further comprises a pair of coil boards **22, 24**, substantially coplanar with the tracking/focus drive directions, and mounted onto the open ends of the lens holder **20**. The coil boards **22, 24** each comprise a centrally fixed rectangular height control coil **32**. A pair of rectangular tracking coils **33, 35** are provided, one each on either side of the height control coil **32** to provide tracking actuation, for each coil board **22, 24**.

The corrector lens assembly 15 is received between a pair of composite plate magnets 52, 54, which are mutually parallel and which are also parallel to the coil boards 22, 24. The plate magnets 52, 54 are also spaced such as to provide a suitable air gap between each plate magnet 52, 54 and the corresponding coil board 22, 24, respectively. Accordingly, the plate magnets 52, 54 are mounted onto a U-shaped magnet mount 72, which is itself fixed onto a base 70. The corrector lens assembly 15 is also supported by and mounted onto the base 70, via a number, typically eight, of resilient support elements such as wires 75, which are connected to the lens holder 20 at one end thereof, and rigidly mounted to a support bracket 76 at the other end of. The support bracket 76 is in turn mounted onto the base 70. The wires 75 are arranged on two spaced planes, and are arranged substantially parallel to the tangential direction when unstressed, thus allowing movement of the optical head 20 in both the focusing and tracking directions with respect to the base 70. Alternatively, the wires may be replaced with any other suitable elastic suspension means capable of allowing the necessary movement in the tracking and focusing directions. In other embodiments, the wires may be at some desired angle to the tangential direction rather than aligned therewith when unstressed.

The base 70 and the magnet mount 72 each comprise apertures 71, 73, respectively, which are aligned with the optical axis OA of the corrector lens 30 (and of objective lens 130 – see Figure 3) and also with a suitable radiation source of an optical module (not shown), for example a laser, which supplies a radiation beam to the optical information carrier via the lens actuator assembly 10 during operation thereof.

Referring to Fig. 5, the magnet arrangement for plate magnets 52, 54 is illustrated. Plate magnet 54 comprises a pair of central bar –shaped magnets mounted one over the other and arranged such that the upper magnet 81 has a North Pole facing a coil arm of the height control coil 32 of coil board 24, and the lower magnet 82 has a South Pole facing another coil arm of the height control coil 32 of coil board 24. The plate magnet 54 also comprises a pair of

magnets **83**, **84** adjacent to the central magnets **81**, **82** along the tracking direction. The magnets **83**, **84** are mounted one next to the other and arranged such that magnets **83** **84** have a North Pole and a South Pole, respectively, facing spaced coil arms of the tracking coils **33** of coil board **24** The plate magnet **54** also comprises another pair of magnets **85**, **86** adjacent to the central magnets **81**, **82** and on the other side thereof along the tracking direction. The magnets **85**, **86** are mounted one next to the other and arranged such that magnets **85**, **86** have a North Pole and a South Pole, respectively, facing the coil arms of tracking coils **35** of coil board **24**. A similar arrangement is provided for the second plate magnet **52**

Thus, an electromagnetic actuator is provided for the auxiliary lens **30**, comprising the height control coils **32** and the magnets **81**, **82**, for actuating the lens **30** in the focusing direction. Another electromagnetic actuator is provided for the auxiliary lens **30**, comprising the tracking coils **33**, **35** and the magnet pairs **83**, **84** and **85**, **86** for actuating the lens **30** in the tracking direction

In operation, the current in the height control coils **32** is proportional to the height servo error signal corresponding to the focus drive direction. This signal relates to the displacement between the corrector lens **30** and the surface of the data carrier, typically in the form of a disc. The electro-magnetic force which is generated by these coils is proportional to the product of the coil current **I** and the external magnetic flux density **H** (i.e., that is caused by the magnets **81**, **82** of the plate magnets **52**, **54**), and the direction of the electro-magnetic force **F** is along the coil surface and parallel to the optical axis **OA**. Thus the height control coils **32** move up and down along the focusing direction according to the polarity of the coil current, until the height servo error signal is reduced to zero. With respect to the tracking drive coils **33**, **35**, a similar situation exists to that described for the height control coils **32**, except that the each of the tracking drive coils **33**, **35** interact with the corresponding magnet pairs **83**, **84** and **85**, **86**, respectively, and move to the right or the left along the tracking direction

according to the servo signals supplied by the appropriate tracking optical unit, for example according to the method as described in US 2003/0174594 (assigned to the present assignee), the contents of which are incorporated herein in their entirety.

The lens actuator assembly **10** according to the present invention is adapted for scanning any one of a plurality of different depths within the carrier, and thus comprises a main lens assembly **100** that performs the majority of the light bending required for the focusing of radiation at a particular depth in the information carrier. The corrector lens **30**, when used with the main lens assembly **100**, may comprise, for example a meniscus lens, and in any case mainly compensates for the changing spherical aberration introduced by the changing of the thickness into which the radiation is being focused, but also provides some focusing of the radiation. The combination and specific optical properties of lenses **130, 30** enable a beam of radiation to be focused at any one of a plurality of depths within the carrier.

Referring in particular to Figs. 3 and 4, in the first embodiment, the main lens assembly **100** comprises an objective or main lens **130** mounted onto a main lens holder **140**. The main lens holder **140** comprises a cylindrical element **145** which is adapted for accommodating the main lens **130**, and two pairs of radial struts **142, 144**, one pair each projecting from either side thereof. The main lens assembly **100** further comprises a pair of coil boards **122, 124**, substantially coplanar with the tracking/focus drive directions, and mounted onto the free ends of strut pairs **142, 144** of the main lens holder **140**. The coil boards **122, 124** each comprise a centrally fixed rectangular focusing coil **132**. The main lens assembly **100** is adapted for movement along the focusing direction within the corrector lens assembly **15**, and independently thereof. Accordingly, a suspension system is provided enabling the main lens **130** to move along the optical axis **OA** with respect to the corrector lens **30**. The suspension system comprises spaced mounting elements. One mounting element includes a pair of upper plate or leaf

springs 182, 184, which are in their unstressed state aligned substantially parallel to the focusing direction, and each is mounted at an inner end thereof to the underside 27 of the lens holder 20. Advantageously, the upper leaf springs are integrally joined one to the other via central ring member 183, which is press-fitted or otherwise fixed onto a circular mount 28 co-axial with the opening 21. The other mounting element of suspension system comprises a pair of lower leaf springs 186, 188, which are in their unstressed state aligned substantially parallel to the focusing direction, and also to the upper leaf springs 182, 184. Each lower leaf spring 186, 188 is mounted at an inner end thereof to the underside 147 of the main lens holder 140. Advantageously, the lower leaf springs are integrally joined one to the other via central ring member 187, which is press-fitted or otherwise fixed onto a circular mount 148 co-axial with the cylindrical element 145. Substantially rigid spacer elements 152, 154 connect the free ends of pairs of leaf springs 182, 186 and 184, 188, respectively. The spacer elements 152, 154 provide a spacing between the upper leaf springs 182, 184 and the lower leaf springs 186, 188, greater than the height of the cylindrical element 145 along the focusing direction.

The spring arrangement for the suspension system allows movement of the main lens 130 along the optical axis OA without introducing any substantial decentering or tilt of the objective lens 130 with respect to the corrector lens 30.

In this embodiment, the plate magnets 52, 54, and in particular the central magnets 81, 82 of each said plate magnet, are also used for providing the magnetic flux used in actuation of the objective focus drive coils, i.e. depth focusing coils 132. In operation, the current in the objective focus drive coils 132 is proportional to the depth servo signal corresponding to the desired depth in which it is desired to read/write information within the three-dimensional information medium, along the focus drive direction. This signal is modified by bulk movement of the information layer due to "wobble" and other instabilities in the attitude of the carrier. The electro-magnetic force which is generated by these

coils **132** is proportional to the product of the coil current **I'** in coils **132** and the external magnetic flux density **H'** (i.e., that is caused by the central magnets **81, 82** of the plate magnets **52, 54**, and the direction of the electro-magnetic force **F'** is parallel to the coil surface and in a direction substantially parallel to the optical axis **OA**. Thus the depth focusing coils **132** move up and down along the focusing direction according to the polarity of the coil current, until the depth servo error signal is reduced to zero.

Thus, another electromagnetic actuator is provided for the objective lens **130**, comprising the depth focusing coils **132** and the magnets **81, 82**, for actuating the lens **130** in the focusing direction

In operation, the lens assemblies **15, 100** are actuated independently one from the other. The objective lens assembly **100** is actuated to maintain the beam of radiation focused at a particular data layer within the carrier, and a depth servo error signal is provided by a suitable sensing system for controlling this actuation, for example as disclosed in the aforementioned US 2003/0174594. The correction lens assembly **15** is actuated in the tracking direction for maintaining the beam within a track, and a tracking error signal is provided by a suitable sensing system for controlling this actuation, for example as disclosed in the aforementioned US 2003/0174594. The correction lens assembly **15** is also actuated in the focusing direction for maintaining a constant distance or displacement between the corrector lens **30** and the surface of the data carrier or disc such as to prevent spherical aberration, and a displacement error signal is provided by a suitable sensing system for controlling this actuation.

Thus the lens assemblies **100** and **15** are arranged in a spaced-apart relationship along an optical axis **OA** defined by these lens assemblies, with the corrector lens **30** being accommodated downstream of the main lens **130**, i.e., closer to the information carrier. The lenses **130** and **30** are appropriately designed to correct for spherical aberrations, while typically scanning various depths in the carrier by two beams of different wavelengths. At least one of the

lenses' surfaces is typically aspheric, with no need for complementary shapes of the lens' surfaces.

In the first embodiment, the corrector lens **30** is kept at a certain a substantially fixed distance from the information carrier, typically in the range of about 100 – about 400 microns, and the objective lens **130** is movable. This provides for the simplicity and applicability of the design, as far as mechanics and feedback mechanisms are concerned. Generally, however, at least one of the other elements may be movable as well, namely, as far as degrees of freedom are concerned, one or more optical elements of the system can be moved. In other embodiments, the corrector lens, and possibly both lenses are movable along the optical axis.

The radiation source of the optical module (not shown) that supplies a radiation beam to the optical information carrier via the lens actuator assembly **10** during operation thereof does not necessarily need to be moved in the focusing direction, particularly if collimated or near-collimated radiation is used. Optionally, though, a suitable actuator may also be provided for moving the radiation source in the focusing direction.

The lens actuator assembly of the present invention is particularly useful for reading/writing with respect to a three-dimensional optical disc, typically to a depth ranging from about 0mm to about 3mm. Furthermore, the lens assembly may also be used in many other applications, and finds particular use in a multifunction drive that can read/write to different types of discs, for example with respect to a CD disc of 1.2mm thickness and/or with respect to a DVD disc with 0.6mm thickness, and/or with respect to BluRay discs with 0.1mm thickness. Thus, the lens actuator assembly of the present invention may also be retrofitted with respect to multifunction drives, or be included in the design of new multifunction drives, which can be used with any number of different types of discs, each having data at different depths from the other discs.

A second embodiment of the invention, illustrated in Figs. 6, 7 and 8, comprises all the elements of the first embodiment with a few differences, as described herein *mutatis mutandis*.

Thus, the second embodiment of the lens actuator assembly for an optical head, generally designated with the numeral **10'**, is similar in function and operation to that of the first embodiment, and comprises a corrector lens assembly **15'**, comprising a lens holder **20'**, which is generally box like and for this embodiment is closed at the lower end, having an upper opening **21'** in which a correcting lens **30'** is mounted, and a lower opening **23'** aligned therewith along the optical axis **OA** of the lens actuator assembly **10'**. The corrector lens assembly **15'** further comprises a pair of coil boards **22'**, **24'** (each comprising height coils **32'**, and tracking coils **33'**, **35'**), substantially coplanar with the tracking/focus drive directions, and mounted onto the opposed open ends of the lens holder **20'** in a similar manner to the elements described for the first embodiment. The corrector lens assembly **15'** is received between a pair of composite plate magnets **52**, **54**, which are mounted onto a U-shaped magnet mount **72** and base **70**, as described for the first embodiment. The corrector lens assembly **15'** is also supported by and mounted onto the base **70**, via a number, typically eight, of resilient support elements such as wires **75**.

The lens actuator assembly **10'** according to the second embodiment also comprises a main lens assembly **100'**, which comprises an objective or main lens **130'** mounted onto a main lens holder **140'**. As with the first embodiment, the main lens holder **140'** also comprises a cylindrical element **145'** which is adapted for accommodating the main lens **130'**, and two pairs of radial struts **142'**, **144'**, one pair each projecting from either side thereof, and a pair of coil boards **122'**, **124'**, each having a depth focusing coil **132'**.

The main lens assembly **100'** in the second embodiment differs from that of the first embodiment as follows. The suspension system comprises four spaced mounting elements. Referring particularly to Figs. 7 and 8, a first mounting element includes a pair of upper plate or leaf springs **182'**, **184'**, which are in

their unstressed state aligned substantially parallel to the focusing direction, and each is mounted at an inner end thereof to the underside **27'** of the lens holder **20'**. Advantageously, the upper leaf springs are integrally joined one to the other via central ring member **183**, which is press-fitted or otherwise fixed onto a circular mount **28** co-axial with the opening **21**. A second mounting element, similar to the first mounting element, also comprises a pair of leaf springs **282'**, **284'** integrally joined one to the other via central ring member **283'**, which is press-fitted or otherwise fixed onto a circular mount **29'** co-axial with the opening **23**.

A third mounting element of suspension system comprises another pair of leaf springs **186'**, **188'**, which are in their unstressed state aligned substantially parallel to the focusing direction, and also spaced with respect to the upper leaf springs **182'**, **184'**. Each leaf spring **186'**, **188'** is mounted at an inner end thereof to the upper side **147'** of the main lens holder **140'**. Advantageously, the leaf springs **186'**, **188'** are integrally joined one to the other via central ring member **187'**, which is press-fitted or otherwise fixed onto a circular mount **148** co-axial with the cylindrical element **145'** at an upper end of main lens holder **140'**. A fourth mounting element, similar to the third mounting element, also comprises a pair of leaf springs **286'**, **288'** integrally joined one to the other via central ring member **287'**, which is press-fitted or otherwise fixed onto a circular mount **248'** co-axial with the cylindrical element **145'** at a lower end of main lens holder **140'**.

Substantially rigid spacer elements **152'**, **154'** connect the free ends of groups of leaf springs **182'**, **186'**, **286'**, **282'** and **184'**, **188'**, **288'**, **284'** respectively.

Thus, as with the first embodiment, the spring arrangement for the suspension system allows movement of the main lens **130'** along the optical axis **OA** without introducing any substantial decentering or tilt of the objective lens **130'** with respect to the corrector lens **30'**.

Operation of the second embodiment is substantially similar to that described for the first embodiment, *mutatis mutandis*.

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In another aspect of the present invention, the focusing coils for the objective lens assembly may be similar to those described with respect to the first or second embodiment, but rather than being aligned along planes parallel to the focus/tracking plane the coils are instead arranged to be in alignment parallel to the focus/tangential plane. Accordingly, a second pair of plate magnets also aligned with this plane is provided, each plate magnet comprising a pair of vertically disposed magnets in a similar manner to magnet pair **81, 82**. This arrangement also provides a mechanical force to the objective lens assembly in the focusing direction.

In yet another aspect of the present invention, the height control coils for the corrector lens assembly may be similar to those described with respect to the first or second embodiment, but rather than being aligned along planes parallel to the focus/tracking plane the coils are instead arranged to be in alignment parallel to the focus/tangential plane. Accordingly, a second pair of plate magnets also aligned with this plane is provided, each plate magnet comprising a pair of vertically disposed magnets in a similar manner to magnet pair **81, 82**. This arrangement also provides a mechanical force to the corrector lens assembly in the focusing direction.

In another aspect of the present invention, the focusing coils for the objective lens assembly and the height control coils for the corrector lens assembly may be similar to those described with respect to the first or second embodiment, but rather than being aligned along planes parallel to the focus/tracking plane both sets of coils are instead arranged to be in alignment parallel to the focus/tangential plane. Accordingly, a second pair of plate magnets also aligned with this plane is provided, each plate magnet comprising a pair of vertically disposed magnets in a similar manner to magnet pair **81, 82**. This arrangement also provides a mechanical force independently to each one of the objective lens assembly and the corrector lens assembly in the focusing direction.

CLAIMS:

1. A lens actuator assembly for an optical head comprising:

a lens system comprising a first lens arrangement and a second lens arrangement for focusing a beam of radiation in a focusing direction;

a first electromagnetic actuator for actuating at least said first lens arrangement in a focusing direction;

a second electromagnetic actuator for actuating at least said second lens arrangement in a focusing direction;

wherein a common magnet arrangement provides a suitable magnetic field common to both said actuators, enabling operation of each said actuator when a suitable electric current is provided thereto.

2. A lens actuator assembly according to claim 1, wherein said first actuator comprises a pair of first coils one each mounted to opposed ends of a housing, said housing accommodating said first lens at an aperture thereof aligned in said focusing direction.

3. A lens actuator assembly according to claim 2, wherein said magnet arrangement comprises a first plate magnet mounted to a base in opposed relationship to one said first coil and a second plate magnet mounted to said base in opposed relationship to the other said first coil.

4. A lens actuator assembly according to claim 3, wherein said housing is elastically mounted to said base such as to enable said housing to move in at least said focusing direction while maintaining alignment between said first coils and said first and second plate magnets.

5. A lens actuator assembly according to claim 4, wherein said housing is mounted to said base via a plurality of resilient members connected at one end thereof to said base and at another end thereof to said housing.

6. A lens actuator assembly according to claim 4, wherein said first and second plate magnets each comprise a first pair of bar magnets aligned in series

in the focusing direction and arranged such that for each said pair of bar magnets, each bar magnet exposes a different pole with respect to a said first coil that is mounted in opposition thereto.

7. A lens actuator assembly according to claim 6, wherein said first coils are substantially rectangular, each said first coil comprising a pair of coil arms each of which is substantially aligned with a corresponding pole of a said first pair of bar magnets that is mounted in opposition to said first coil.

8. A lens actuator assembly according to claim 6, wherein said second lens arrangement is accommodated in a lens holder at an aperture thereof aligned in said focusing direction, wherein said lens holder is elastically mounted to said housing via a suspension system.

9. A lens actuator assembly according to claim 8, wherein said second actuator comprises a pair of second coils mounted to opposed ends of said lens holder.

10. A lens actuator assembly according to claim 9, wherein each said second coils is in substantially opposed relationship with respect to one or another said first pair of bar magnets.

11. A lens actuator assembly according to claim 10, wherein said second coils are substantially rectangular, each said second coil comprising a pair of coil arms each of which is substantially aligned with a corresponding pole of a bar magnet of said pair of bar magnets that is mounted in opposition to said first coil.

12. A lens actuator assembly according to claim 8, wherein said suspension system is configured to enable said lens holder to move in at least said focusing direction while maintaining alignment between said second coils and said first and second plate magnets.

13. A lens actuator assembly according to claim 12, wherein said suspension system is configured to enable said lens holder to move in at least said focusing direction while substantially maintaining alignment between said first lens

arrangement and said second arrangement along an optical axis of said lens system.

14. A lens actuator assembly according to claim 13, wherein said suspension system comprises first and second mounting elements spaced one from the other along the focusing direction and each extending transverse from the focusing direction, each mounting element being elastically deformable along the focusing direction.

15. A lens actuator assembly according to claim 14, wherein said first mounting element is mounted to said housing, and wherein said second mounting element is mounted to said lens holder.

16. A lens actuator assembly according to claim 15 wherein said first mounting element is connected to said second mounting element via substantially rigid spacing members at the transverse ends of said mounting elements.

17. A lens actuator assembly according to claim 14, wherein said first and second mounting elements each comprise a pair of leaf springs joined to a central mounting ring.

18. A lens actuator assembly according to claim 13, wherein said suspension system comprises a first pair and a second pair of mounting elements spaced one from the other along the focusing direction and each extending transverse from the focusing direction, each mounting element thereof being elastically deformable along the focusing direction.

19. A lens actuator assembly according to claim 18, wherein said first pair of mounting elements is mounted to said housing at opposed inner sides thereof, and wherein said second pair of mounting elements is mounted to said lens holder one each at an upper end and lower end thereof.

20. A lens actuator assembly according to claim 19 wherein said first pair of mounting elements is connected to said second pair of mounting elements via substantially rigid spacing members at the transverse ends of said mounting elements.

21. A lens actuator assembly according to claim 20, wherein each said mounting element said first and second pair of mounting elements comprises a pair of leaf springs joined to a central mounting ring.

22. A lens actuator assembly according to claim 2, further comprising a third electromagnetic actuator for actuating at least said first lens arrangement in a tracking direction substantially orthogonal to said focusing direction.

23. A lens actuator assembly according to claim 22, wherein said third actuator comprises at least one pair of third coils mounted to said opposed ends of said housing.

24. A lens actuator assembly according to claim 23, wherein an auxiliary magnet arrangement provides a suitable magnetic field to said third actuator, enabling operation of said third actuator when a suitable electric current is provided thereto.

25. A lens actuator assembly according to claim 24, wherein said auxiliary magnet arrangement comprises, for each said third coil, a second pair of bar magnets mounted to said base in opposed relationship to said third coil.

26. A lens actuator assembly according to claim 25, wherein each said second pair of bar magnets is aligned in series in the tracking direction and arranged such that for each said second pair of bar magnets, each bar magnet exposes a different pole with respect to a said third coil that is mounted in opposition thereto.

27. A lens holder assembly according to claim 26, wherein each said third coil is positioned adjacent to a corresponding said first coil at each said end of said housing along said tracking direction.

28. A lens actuator assembly according to claim 27, wherein said third coils are substantially rectangular, each said third coil comprising a pair of coil arms each of which is substantially aligned with a corresponding pole of a said second pair of bar magnets that is mounted in opposition to said third coil.

29. A lens actuator assembly according to claim 1, wherein said second lens is an objective lens and said first lens is an auxiliary lens.

30. A lens actuator assembly according to claim 29, wherein said lens system is adapted for enabling a beam of radiation to be focused at any desired depth within a three-dimensional optical data carrier.

31. A lens actuator assembly according to claim 30, wherein said depth is in the range of about 0 to about 3mm.

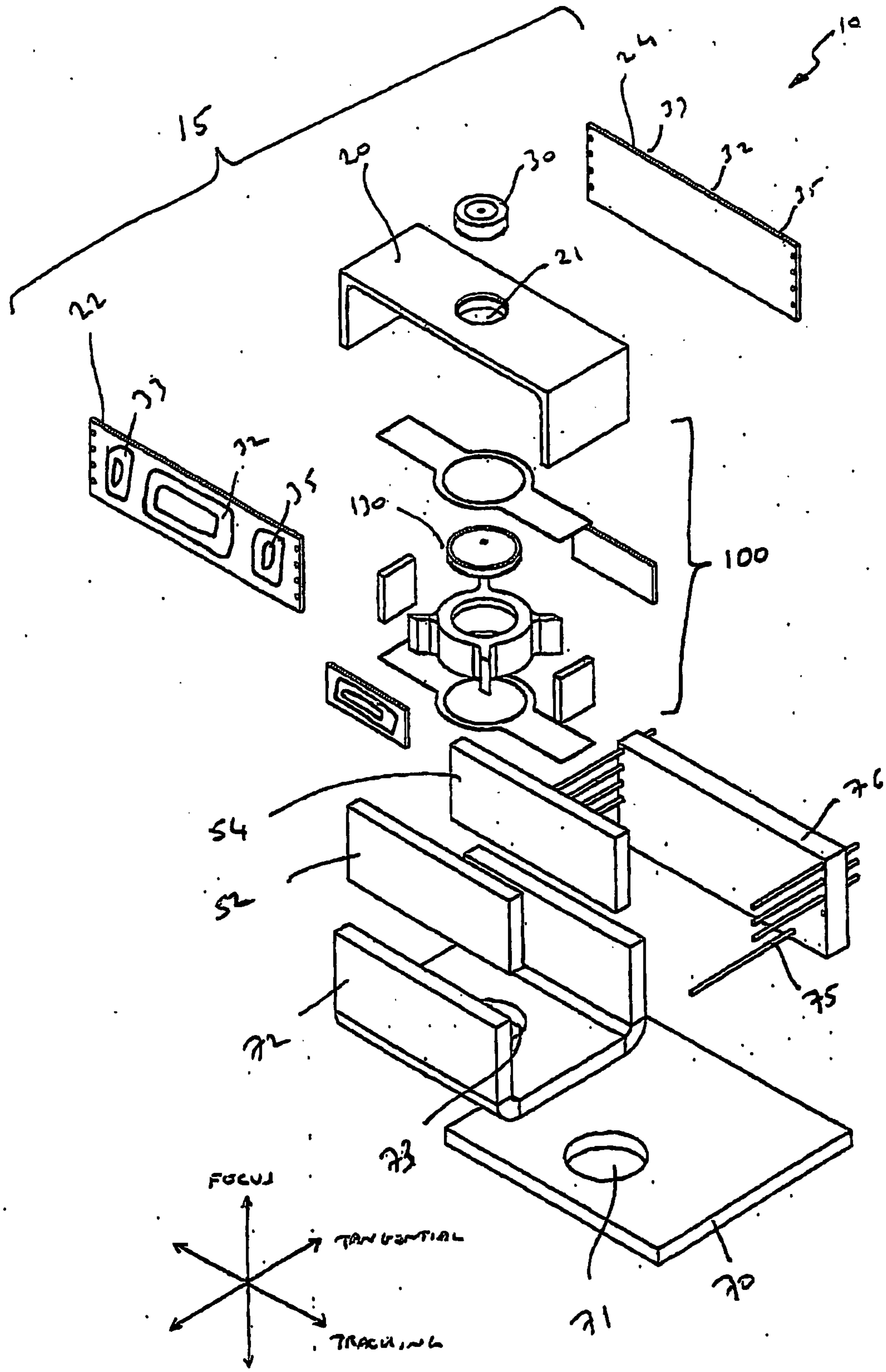
32. A lens actuator assembly according to claim 29, wherein said lens system is adapted for enabling a beam of radiation to be focused at any desired depth within a range of depths such as to enable said beam to be focused at a data layer of an information carrier, wherein said information carrier may include any one of a range of different types of information carriers each having at least one data layer at a different depth within said range of depths.

33. A lens actuator assembly according to claim 32, wherein said different types of information carriers include at least one of a CD, a DVD and a BluRay disc.

34. A lens actuator assembly according to claim 29, wherein said first lens arrangement is positioned about 100 microns to about 400 microns from the surface of an information carrier that it is intended to read/write information with respect to.

35. A lens actuator assembly according to claim 29, wherein said first lens arrangement comprises a meniscus lens.

36. A lens actuator assembly according to claim 29, wherein said second lens arrangement comprises a biconvex lens.



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72
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71
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FOCUS
TANGENTIAL
TRACKING

FIG 1

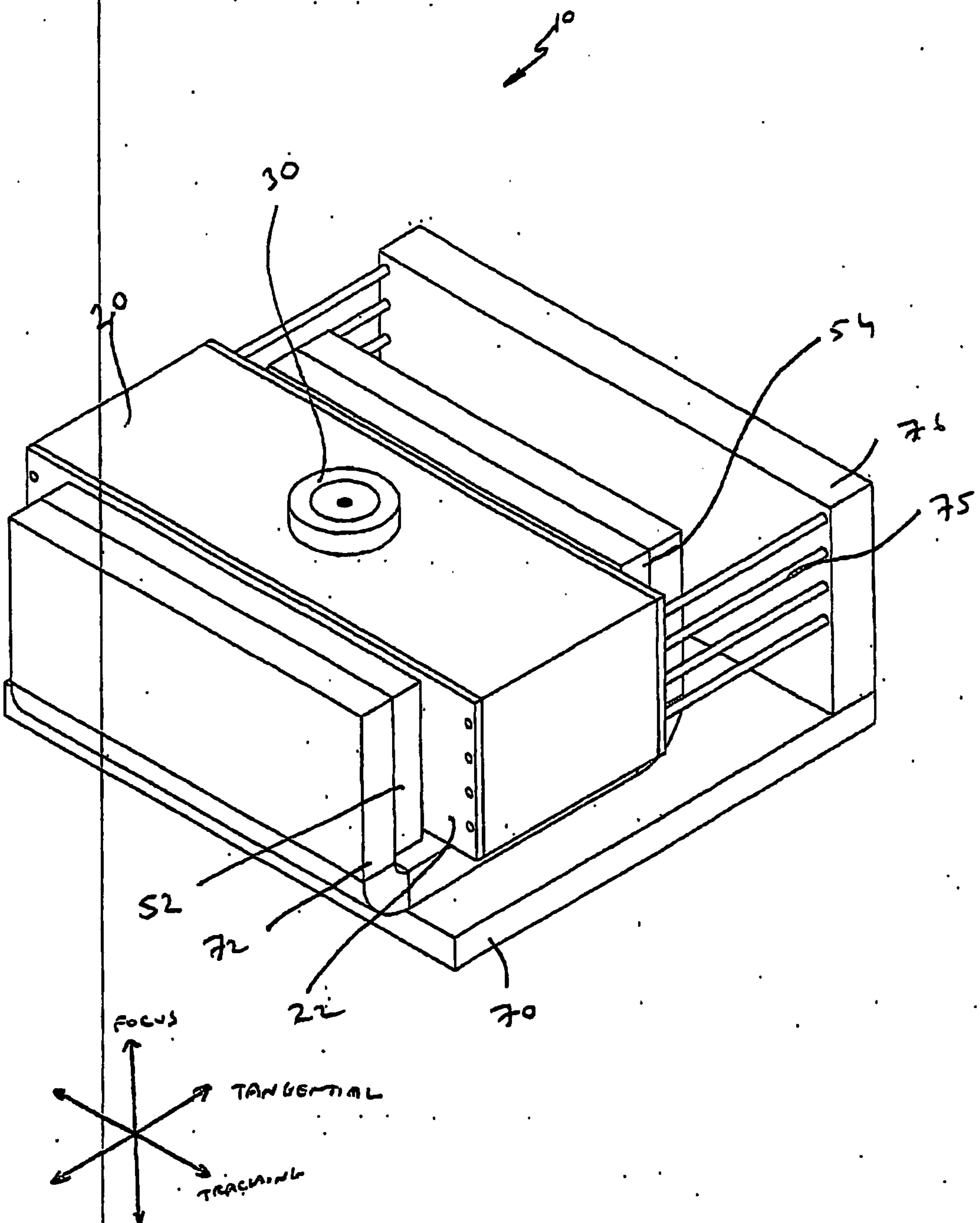
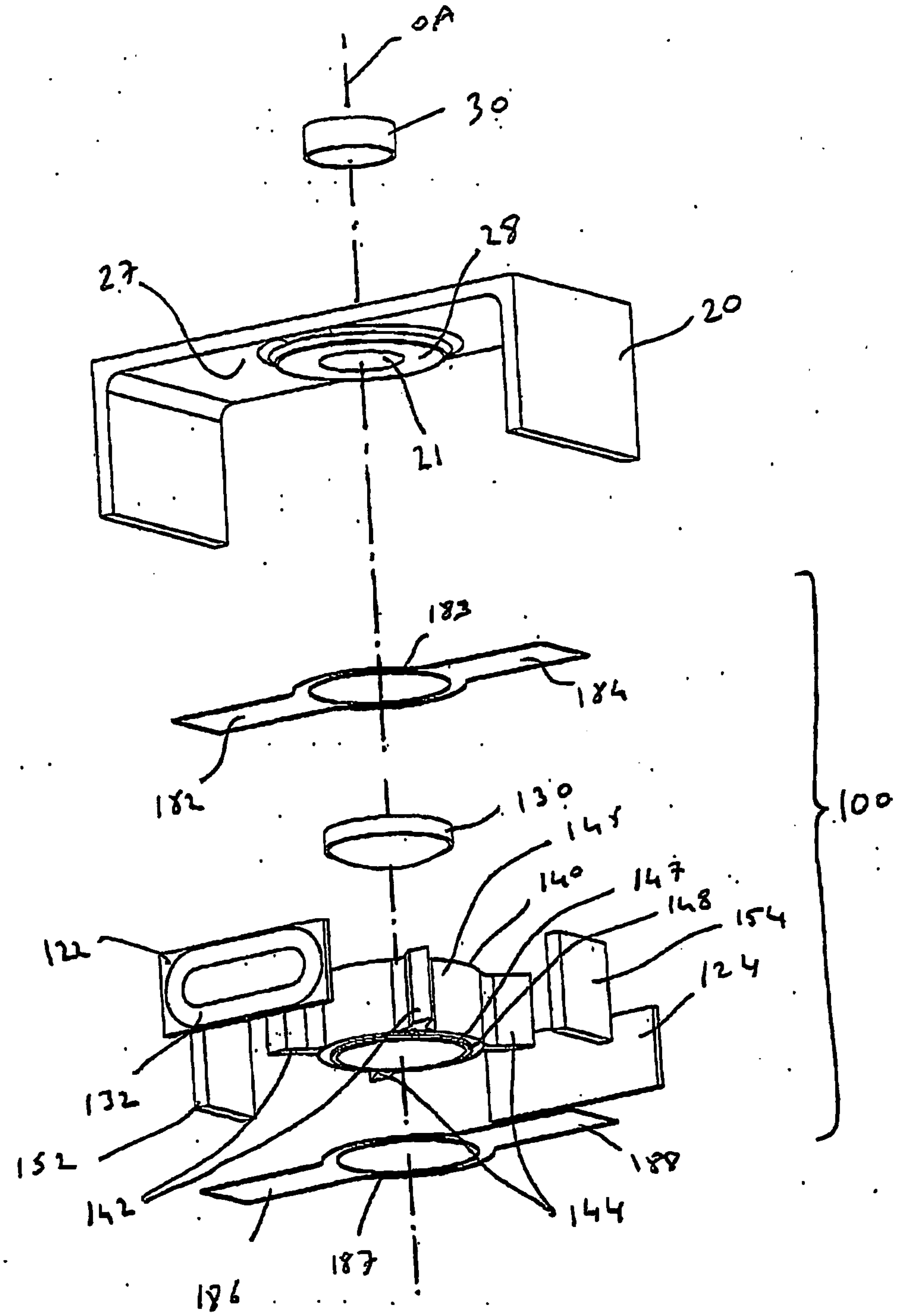


FIG 2



OA
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28
27
20
21
183
184
182
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145
140
147
148
154
122
124
132
152
188
142
144
187
186
100

FIG 3

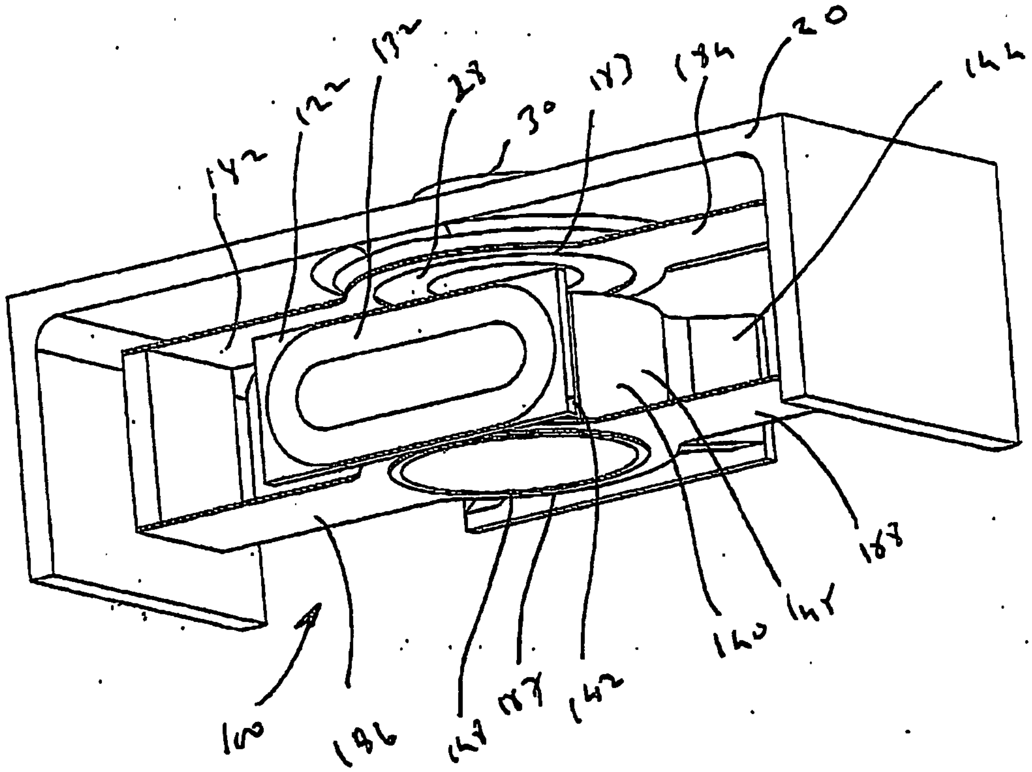
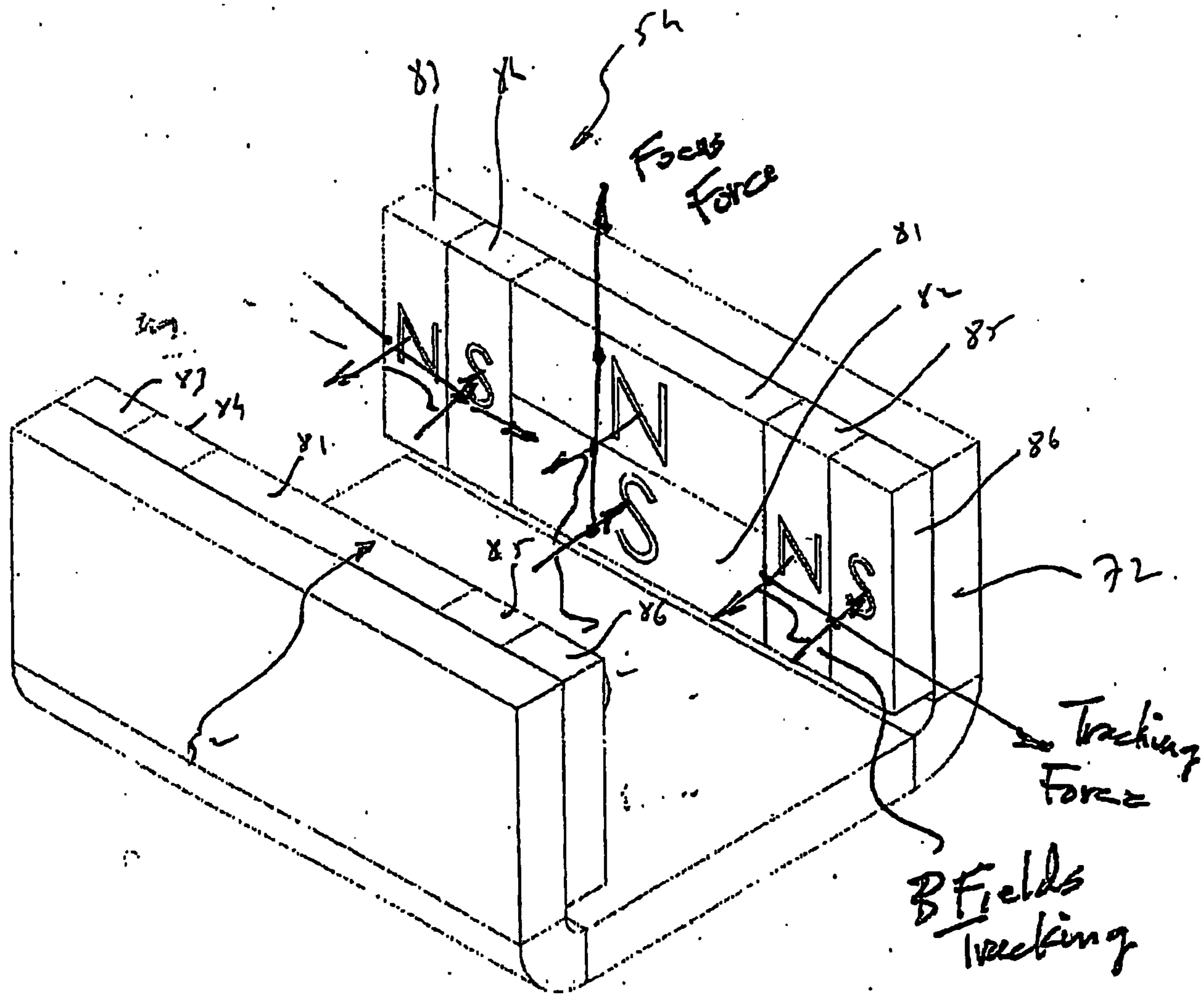


FIG 4


54
83
84
Focus
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81
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FIG. 5

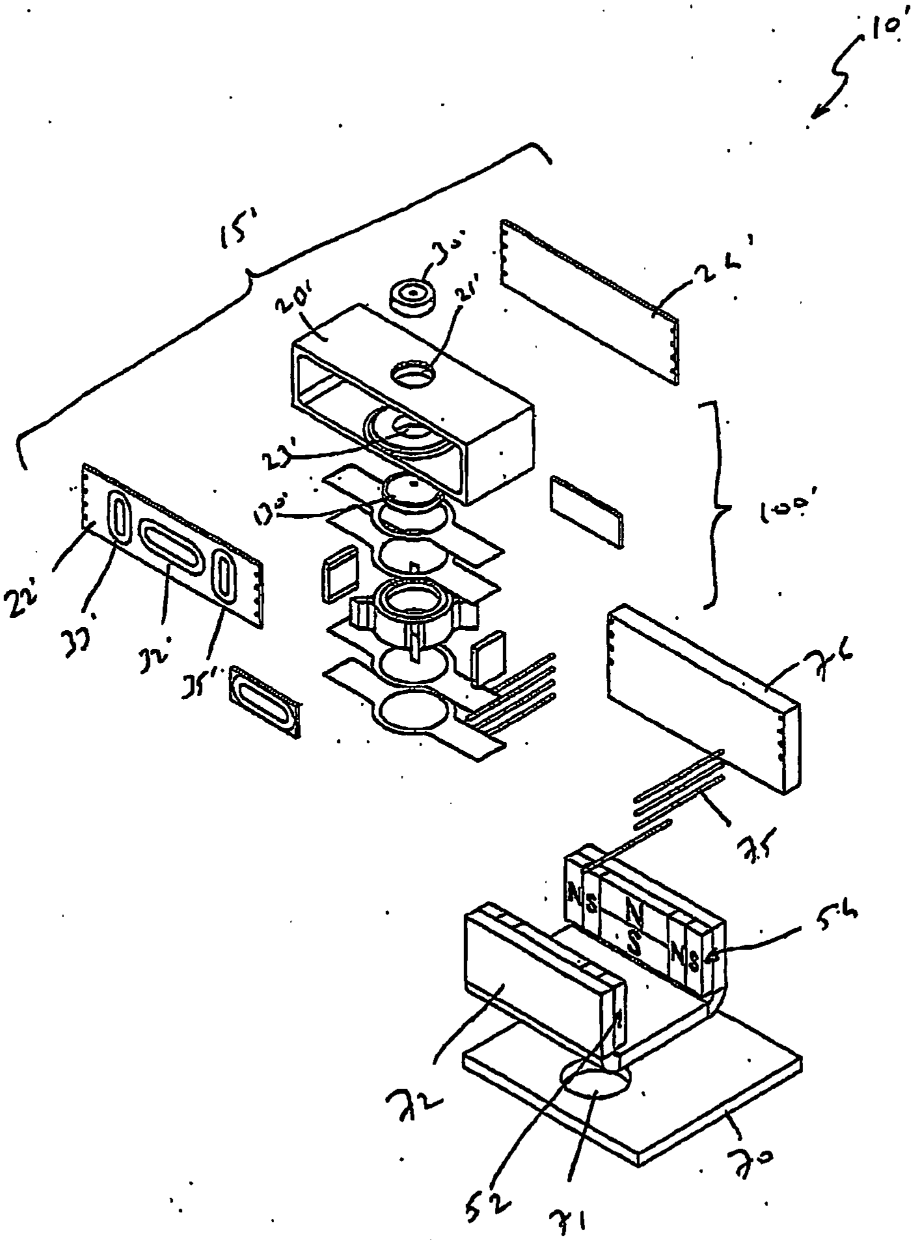
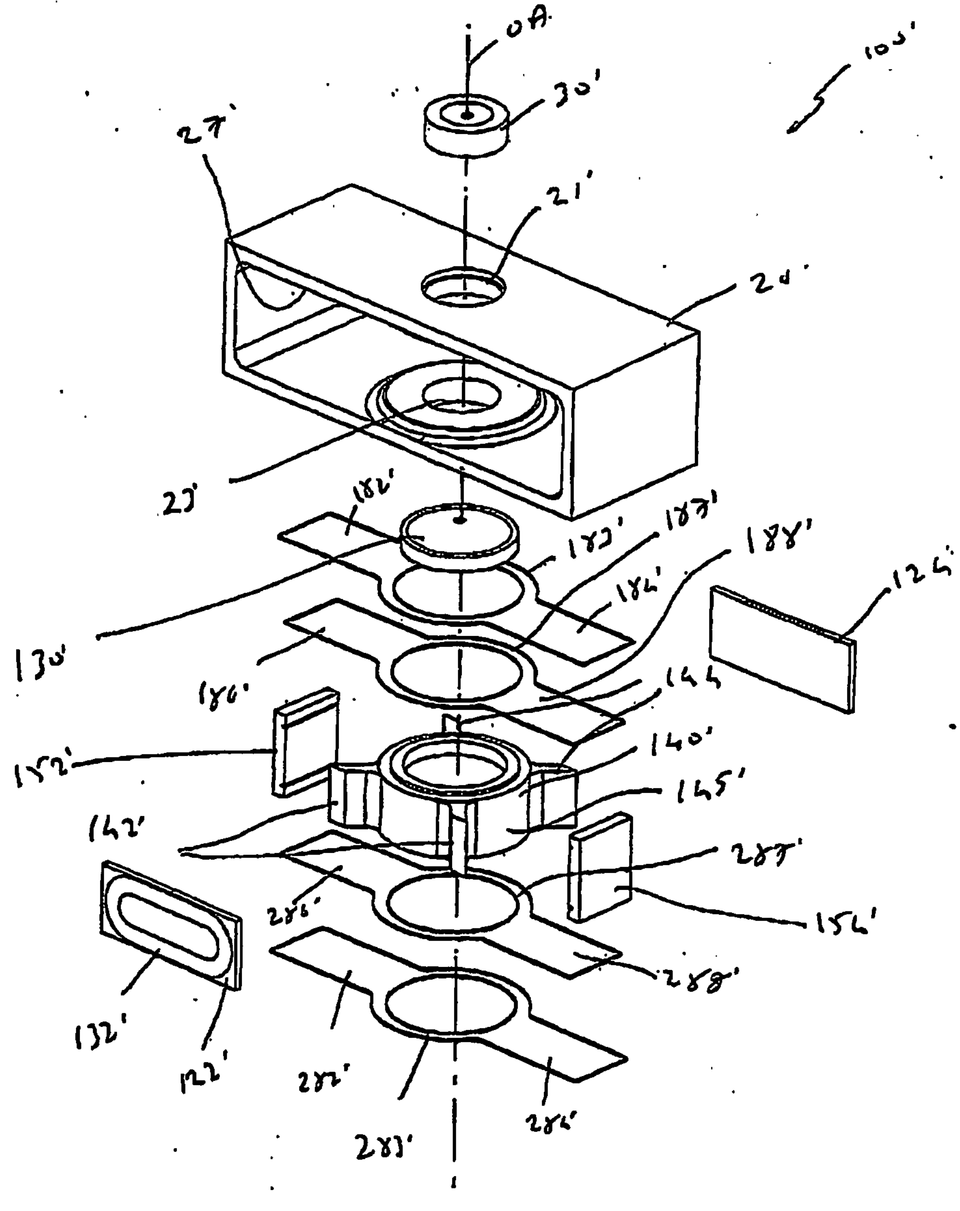


FIG 6


OA
30'
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154'
132'
122'
288'
282'
283'
286'

FIG 7

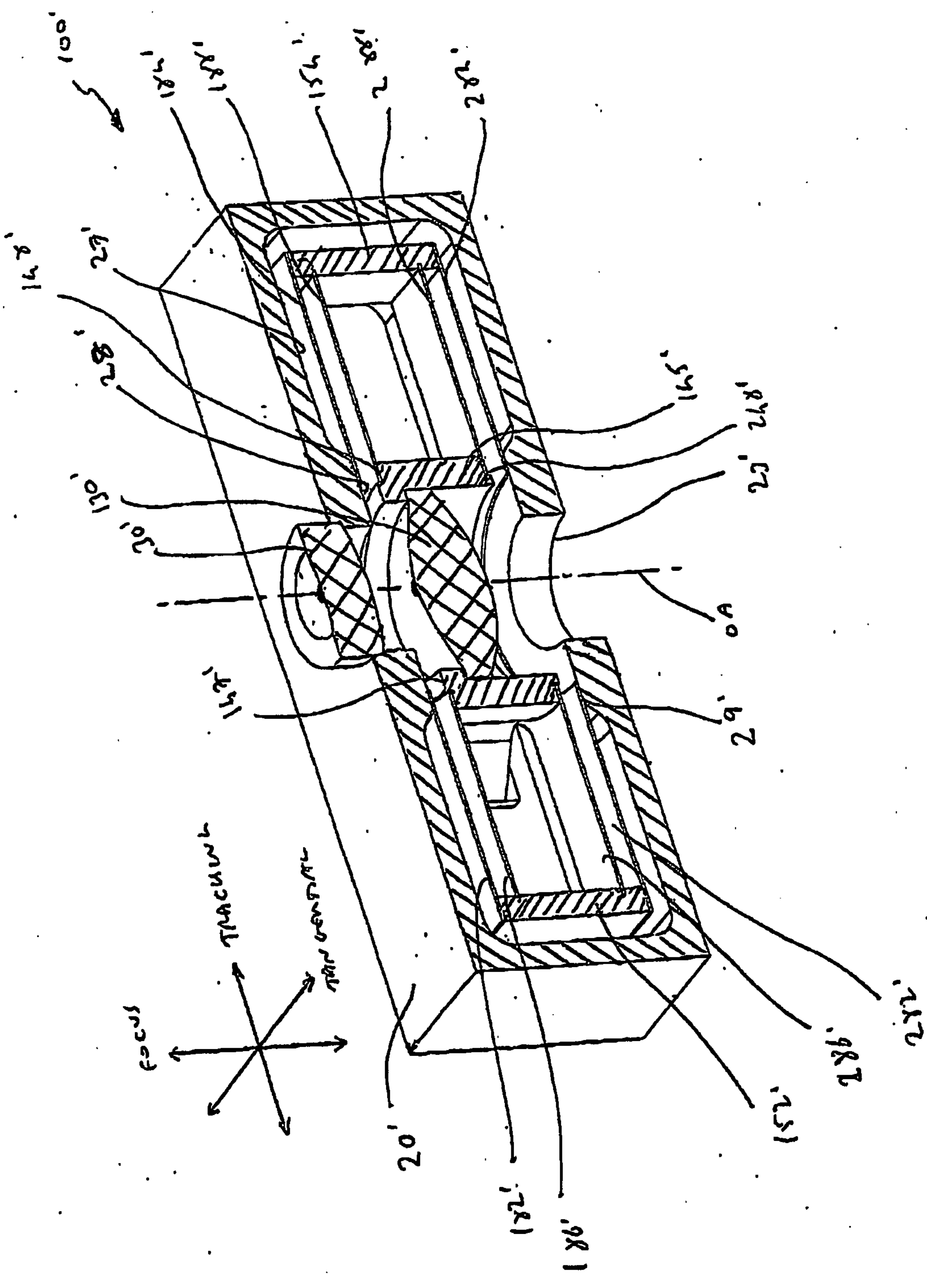

FIG 8